



The Faster, Better, Cheaper Approach To Space Missions:

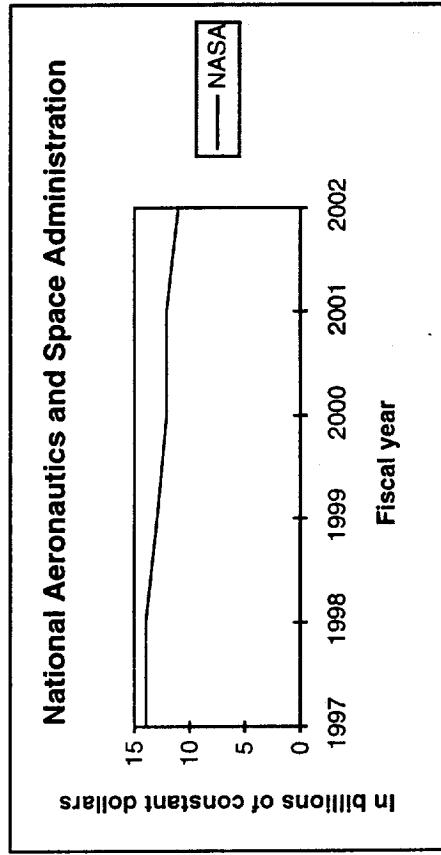
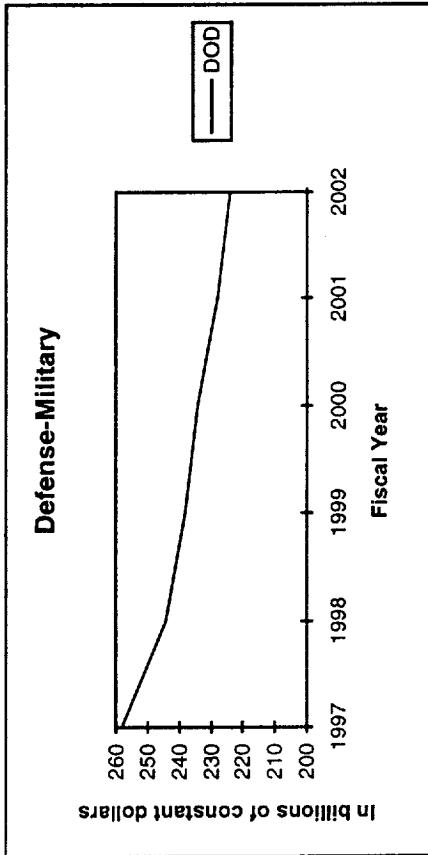
An Engineering Management Assessment

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May 2000*

What Drives

"Faster, Better, Cheaper"?

- **Budgetary downturns**
 - DOD budget decreases due to collapse of Soviet Union
 - NASA budget decreases driven by budget deficits
- **Globalization of the economy and the quest for quality**



WHY SPACE PROGRAMS ARE COSTLY

- Physical environment of space
 - Low gravity drives fluid management costs
 - Vacuum drives material costs and thermal control costs
 - Radiation drives electronics costs
- Catastrophic consequences of an expensive failure in a remote place
 - Relatively small scale of the business base
 - Relatively few suppliers/less competition
 - Small activity level over which to amortize non-recurring costs/fixed costs/sustaining costs/etc.
- Government involvement
 - Changing requirements
 - Over specification
 - Unstable budget
 - Cost plus fee environment
- Immaturity of technology readiness
 - Space typically TRL 4-7 (versus TRL 8-9 for commercial programs)
 - Less use of COTS hardware and software



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Background

- Since about 1990, the aerospace industry has undertaken numerous initiatives designed to improve the cost, schedule and performance effectiveness of its projects.
- While policy level guidance has been provided by NASA, USAF, and BMDO, specific implementations have been the responsibility of individual project teams.
- Many approaches have been attempted - some successful and some not.
- It is the intent of this research to examine the track record of these initiatives.



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Aerospace Project Management (Old Culture)

- All projects were thought to have four major variables
 - Performance
 - Cost
 - Schedule
 - Risk (of performance, cost, schedule)
- It was believed that there were irrevocable relationships between these variables
 - Performance could only be purchased with additional cost and/or schedule or risk
 - Cost and/or schedule could only be reduced at the expense of performance and/or risk
 - Risk could only be reduced with additional cost and/or schedule or less performance



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Aerospace Project Management (New Culture)

- Projects still have the same variables
 - Performance, cost, schedule, risk
- But improvements in these characteristics are no longer considered mutually exclusive
- Successful projects are simultaneously improving performance, cost and speed to market
- The effects on risk is somewhat more problematic
 - Some projects purposely accept risk to buy down cost/schedule
- Approaches and lessons learned in high risk projects are not universally applicable
 - Flagship projects are more risk adverse



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Scope of Analysis Limited to Engineering Management Culture

IN SCOPE

Engineering Management Culture

- Engineering process
- Integrated product development teams
- Technology readiness
- Design to cost
- Etc.

Business process

- Streamlined procurement
- Outsourcing
- Full cost accounting
- ISO 9000

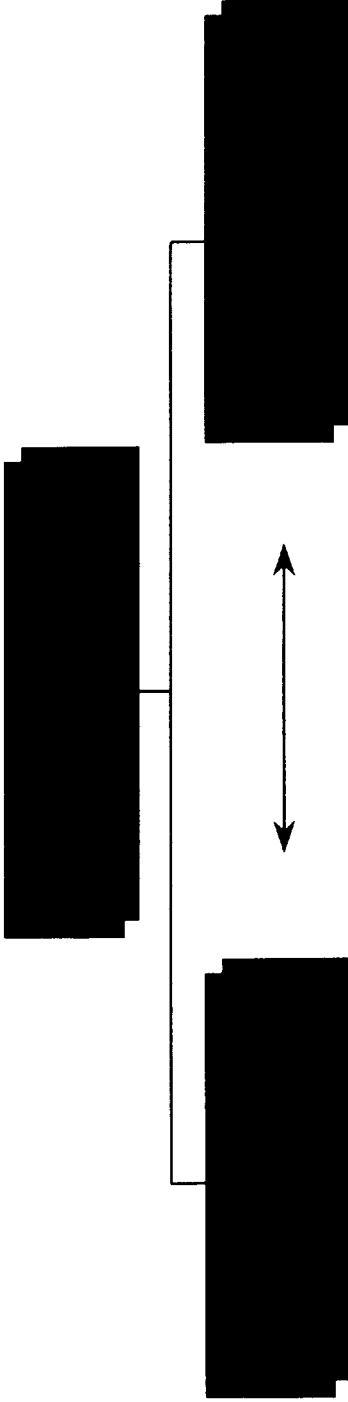
OUT OF SCOPE

Systems Engineering Trades

- Reduced functionality to reduce cost
 - Low mass, power, data rate, number sensors, etc.
- Specific design choices
 - Material selection (Al, Ti, Composites, etc.)
 - Manufacturing process (machining, casting, etc.)
 - Tolerances
 - Parts count
 - Propellant selection
 - Levels of redundancy
 - Class S vs Class B parts
 - Safety factor specification
 - etc.
- Creative bookkeeping
 - Uncosted GFE
 - Free excess assets
 - Free CS labor
 - Off book costs
 - Cost centers w/o overhead
 - Uncompensated overtime

The Faster, Better, Cheaper Approach To Space Missions: An Engineering Management Assessment

Overall Approach



- Literature review of space mission management approaches
- Develop hierarchy of effective management approaches (especially from FBC missions identified in quantitative analysis)
- Develop data base of space mission cost, schedules and technical characteristics
 - Normalize data base
 - Analyze space mission cost trend



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Qualitative Analysis

Some Basic Principles Of The New Culture

Engineering Process

- Teams, teams, teams
 - Concurrent engineering
 - Improved productivity
 - Reduced make-it-work change traffic
 - Increased producibility and operability
- Fluidity in organizational structures
 - Product oriented organizations (vs functional)
 - Less “functional fortress” mentality and use of co-location
 - Flatter organization charts
- New tools and cost consciousness imbued into teams
 - Design to cost, cost as an independent variable (CAIV)
 - Shorter schedule templates
 - Collaborative systems engineering design centers
- Closer relationship with customers and suppliers
 - Reduced requirements changes

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Some Basic Principles Of The New Culture (continued)

Engineering Process (continued)

- Use of CAD/CAM, electronic test and evaluation, information technology and paperless management
 - Enhanced design optimization
 - Reduced test hardware and test operations
 - Less paper
- More use of performance specifications for out-of-house projects
 - Zero based specs and standards
 - Reduced documentation, oversight
 - Continuous review process (versus PDR/CDR* "events")
- Maturation of technologies prior to full scale development
 - Technology readiness level 6 requirement
 - PRR* and PDR in phase B
 - Put high risk items on long lead development
 - X projects, smallsats, medium sats
 - Use of COTS

* PDR - Preliminary Design Review

* CDR Critical Design Review

* PRR - Preliminary Requirements Review

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Some Basic Principles Of The New Culture (continued)

Business Process

- Streamlined source evaluations and procurements
- Use of cooperative agreements, strategic partnering and other innovative business procurements
 - Fixed price contracts or incentive fee contracts
- Encouragement of commercially developed projects by industry
- Use of government labs as industry partner via task agreements
- Government adopting full cost accounting/ABC, ISO 9000
- Outsourcing



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Cause and Effect

- As cost analysts, it seems helpful to think of "Faster, Better, Cheaper" initiatives as "causes" which relate to cost "effects"
- Initiatives are causes

- Integration product development teams, concurrent engineering
- Fluid organizations
- Design to cost and related tools
- Use of mature technologies
- Etc.

- Some likely effects include

- Improved labor productivity (thanks to teams, fewer reviews, less paper, etc.)
- Reduced change traffic (thanks to concurrent engineering)
- Reduced design effort (thanks to mature technology and COTS)
- Reduced overhead (thanks to activity based costing)
- Reduced cost growth (thanks to design to cost)

- Many of the initiatives being suggested are complementary and overlapping (IPDT's and CE)

- It remains nearly impossible (and is dangerous) to predict the cost of savings of individual initiatives.

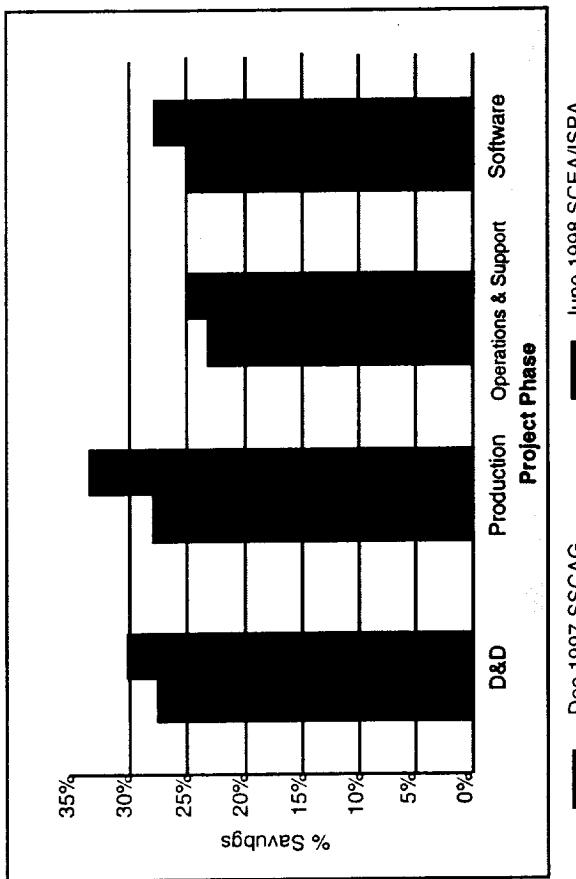
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"New Ways of Doing Business" Survey Results

- Two rounds of surveys of professional cost analysts have been undertaken to gather opinions of progress that has been made by the various "New Ways of Doing Business" initiatives at work in the industry
 - The Space Systems Cost Analysis Group (SSCAG) was surveyed in December 1997 (n=20)
 - The joint conference of the Society of Parametric Analysts (SPA) was surveyed in June 1998 (n=60)
- The summary level results, segregated by project phase, estimates savings of around 25% - 30%
- Per the survey instruments, this data represent savings from initiative inception through full implementation

Summary Average Savings by Project Phase



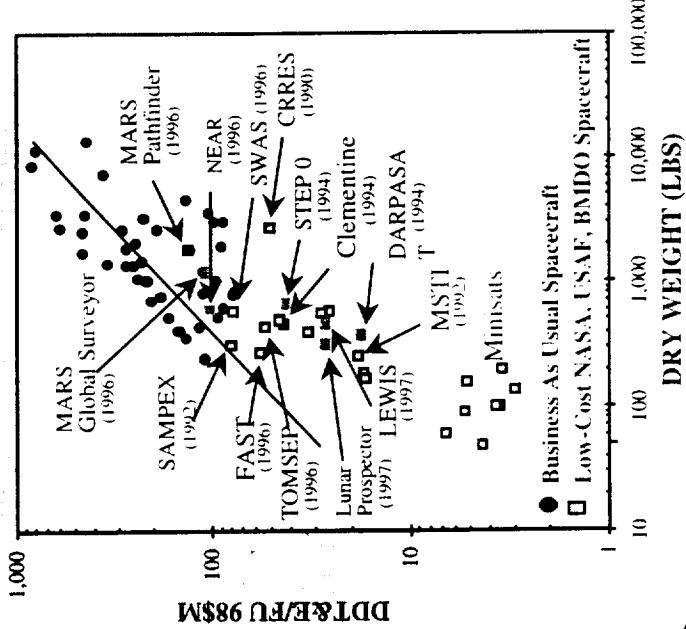
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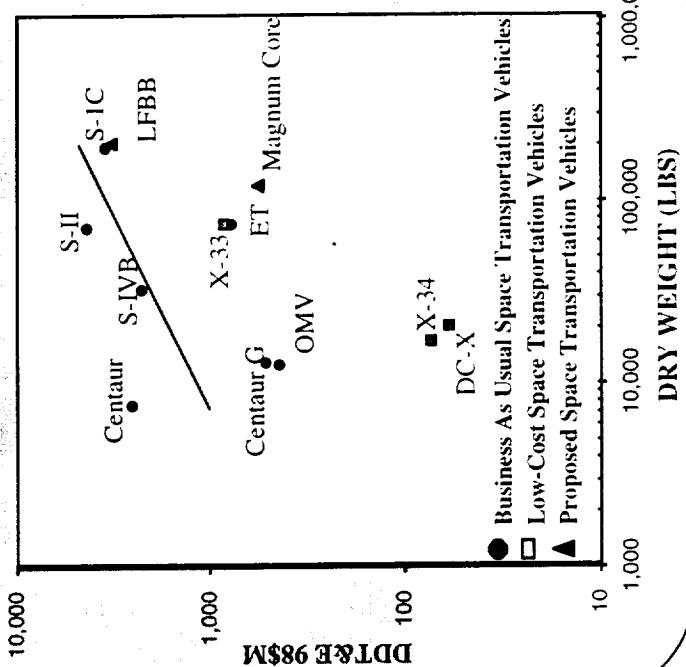
Quantitative Analysis

Recent Space System Cost Trends

(Bus Only) Excluding Instruments Launch & Ops
Spacecraft Development Cost Trends

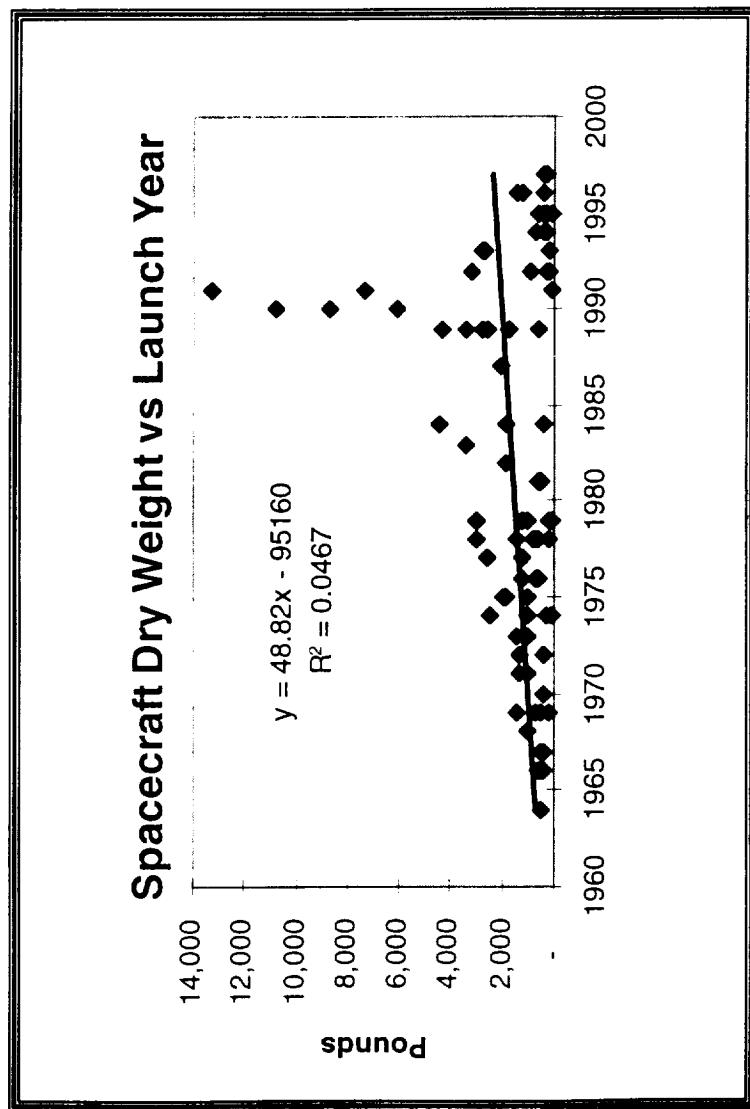


Space Transportation Vehicle Development
Cost Trends (Excluding Engines)



SPACECRAFT DRY WEIGHT TREND

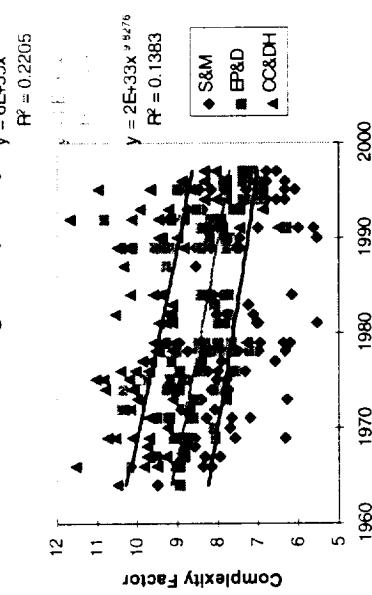
- Total spacecraft population dry weight dispersion is increasing over time
- Traditional spacecraft trending upward in weight
- More smallsats being introduced



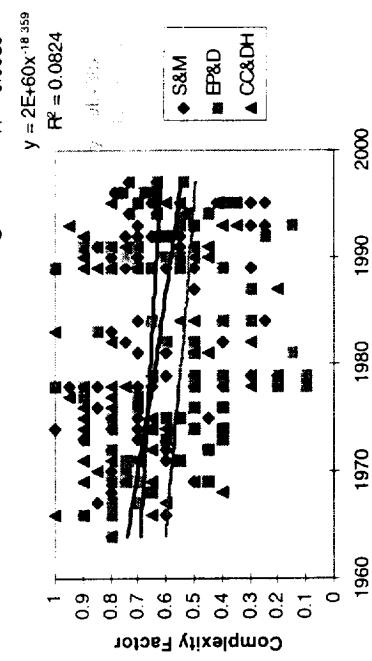
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COMPLEXITY FACTOR TRENDS

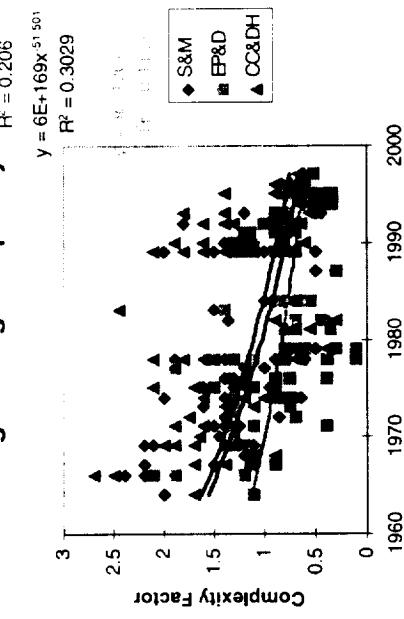
Manufacturing Complexity



Percent New Design



Engineering Complexity



•NAFCOM (NASA, Air Force Cost Model) used as source of

- Manufacturing complexity
- Engineering complexity
- Fraction new design

- Complexity and fraction new design all apparently trending downward (with significant dispersion) 
- reduces cost

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Cost Normalization

- Utilized NAFCOM (NASA, Air Force Cost Model) as source of historical data on 78 spacecraft missions
- Actual cost data reflects inherent differences* in
 - Mission complexity (as measured by NAFCOM manufactory complexity, engineering complexity and fraction new design)
 - Spacecraft size (as measured by spacecraft dry weight)
- These differences were "removed" with a cost normalization algorithm (see next chart) to produce a homogeneous data set
- Resulting data presumably reveals cost trends which were previously masked by differences in ongoing trends in spacecraft complexity and size

* NAFCOM data had previously been normalized to constant price levels (1998\$)



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Cost Normalization Algorithm

Normalized Cost =

$$[\text{Actual Cost}] \left[\frac{1}{\text{WEIGHT}} \right]$$

$[(\text{New})(\text{ECMPLX})(\text{MCPLX$})]_{\text{S}}[0.27]+[(\text{New})(\text{ECMPLX})(\text{MCPLX$})]_{\text{P}}[0.23]+[(\text{New})(\text{ECMPLX})(\text{MCPLX$})]_{\text{C}}[0.50]$

Where	Actual Cost	=	Actual , "unnormalized" total spacecraft cost (98\$M)
Weight	=	Total spacecraft dry weight (lbs)	
New	=	Fraction new design (used as linear multiplier on cost)	
ECMPLX	=	Engineering complexity factor (used as linear multiplier on cost)	
MCPLX\$	=	Manufacturing complexity factor [converted to linear multiplier on cost using 0.025 (MCPLX\$) ²]	
Subscript S	=	Structural and mechanical systems	
Subscript P	=	Electrical power generation and distribution systems	
Subscript C	=	Command, communications and data handling systems	
0.27,0.23 and 0.50	=	System weighting factors based on analysis of total spacecraft population	

Subsystem weighting factors derivation:

NAFCOM	% Cost % cost	$\sum = 100\%$	
Structural and mechanical systems	13%	27%	
Electrical power generation and distribution systems	11%	23%	
Command, communications and data handling systems	23%	50%	
			100%

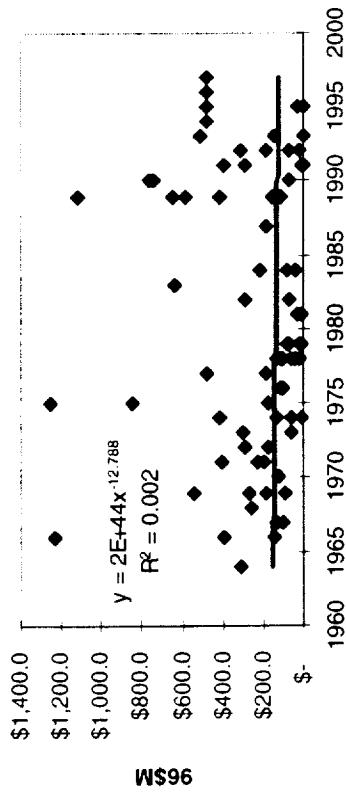
• Structural and mechanical systems
• Electrical power generation and distribution systems
• Command, communications and data handling systems

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UNNORMALIZED COST vs NORMALIZED COST

Unnormalized Cost vs Launch Year



- Unnormalized cost apparently trending downward (with significant dispersion)

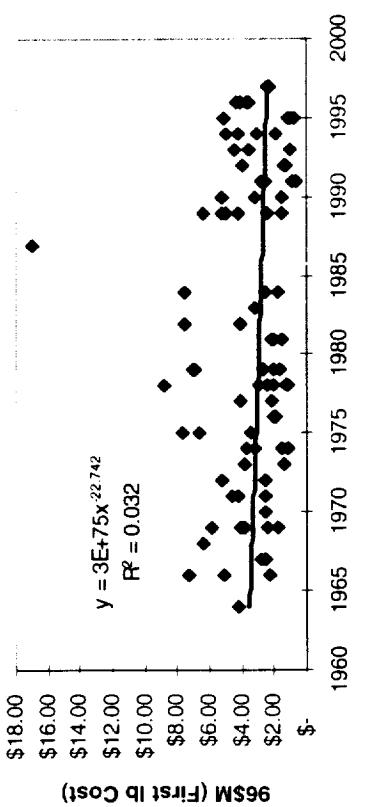
- Cost normalized to “correct” for differences in spacecraft size (i.e. economy of scale differences), complexity and fraction new design:

- “1.0” manufacturing complexity

- “1.0” engineering complexity

- “1.0” fraction new design

Normalized Cost vs Launch Year



- Economies of scale normalized by converting cost to “first pound cost” using assumed $y=ax^b$ with $b=0.5$

- Normalized cost also apparently trends downward suggesting that “faster, cheaper, better” management initiatives are at work over and beyond reductions in complexity and fraction new design.

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Concluding Observations

- From qualitative analysis
 - Many "faster, better, cheaper" initiatives underway
 - Improved engineering process
 - Teams, better organization forms, new tools, better use of technology
 - Improved business process
 - Streamlined procurement, improved government/industry cooperation
 - Considerable claims and anecdotal evidence of progress
- From quantitative analysis
 - Significant dispersion in historical spacecraft data base makes statistical analysis difficult
 - Spacecraft size dispersion increasing
 - Spacecraft complexity is decreasing
 - Spacecraft percent new design is decreasing
 - However, once normalized for these differences, spacecraft mission cost appears to trend downward over time
 - This suggests that "faster, better, cheaper" engineering management initiatives are at work beyond reductions in complexity and fraction new design